MCAT Institute Final Report 90-001

AMES
IN-34-CR
309790
P-11

NCC2-562

Development of a Time-Dependent Incompressible Navier-Stokes Solver Based on a Fractional-Step Method

Moshe Rosenfeld

(NASA-CR-182323) DEVELOPMENT OF A TIME-DEPENDENT INCOMPRESSIBLE NAVIER-STOKES SOLVER BASED ON A FRACTIONAL-STEP METHOD Final Report, 1 Oct. 1988 - 15 Feb. 1990 (MCAT Inst.) 11 p CSCL 20D G3/34
N91-13639
Unclas
0309790

September 1990

MCAT Institute
San Jose, California

[redacted]

MCAT Institute Final Report 90-001

Development of a Time-Dependent Incompressible Navier-Stokes Solver Based on a Fractional-Step Method

Moshe Rosenfeld

FINAL REPORT
FOR THE PERIOD OCTOBER 1, 1988 TO FEBRUARY 15, 1990

September 1990

MCAT Institute
3933 Blue Gum Drive
San Jose, California 95127

DEVELOPMENT OF A TIME-DEPENDENT INCOMPRESSIBLE NAVIER-STOKES SOLVER BASED ON A FRACTIONAL-STEP METHOD

Moshe Rosenfeld

INTRODUCTION

This study has been focused on the development, validation and application of a fractional step solution method of the time-dependent incompressible Navier-Stokes equations in generalized coordinate systems. A solution method that combines a finite-volume discretization with a novel choice of the dependent variables and a fractional step splitting to obtain accurate solutions in arbitrary geometries has been previously developed for fixed-grids, see Ref. (1).

In the present research effort, this solution method is extended to include more general situations, including cases with moving grids. The numerical techniques are enhanced to gain efficiency and generality. This report summarizes briefly the work performed during the period October 1, 1988 through February 15, 1990. Additional details on the various aspects of the study are given in Appendix A.

NUMERICAL ENHANCEMENTS

The fixed grid solution method has been extended to general moving grids. Errors originating from the discrete approximation of the time-dependent coordinate system are minimized by satisfying the discrete geometric conservation laws for the time-varying computational cells. To improve the efficiency of the fixed grid case, two versions of the solution method have been coded: (1) fixed-grid method, (2) moving-grid method.

During the present study, several enhancements of the numerical method have been introduced. A partial list of the modifications is given below:

(1) Implementation of more general boundary conditions implicitly. The allowable boundary conditions are:

(a) Periodic conditions,
(b) Symmetric conditions,
(c) Mixed Dirichlet and Neumann type boundary conditions.

(2) The solution method has been extended to geometrically singular boundaries for the three types of grid topologies (C, O or H grids).

(3) A multi-grid Poisson solver has been written and partially debugged.

(4) Extensive efforts have been made to increase the efficiency of the method by improved vectorization. Presently, the fixed-grid method runs at 80 MFLOPS on the CRAY YMP (single CPU) and about 300 - 400 . 10^{-6} CPU sec/mesh-point/time-step are consumed. The moving-grid code is not yet fully vectorized.

VALIDATION OF THE METHOD

Several additional cases have been solved to validate the method against other numerical and experimental results. In all the cases tested so far, good agreement is obtained. The validation cases include:

Fixed-Grid Case:

(1) Flow in a two-dimensional polar cavity.

(2) Flow in a two-dimensional channel with a fixed constriction and a time variable pressure gradient.

(3) Flow over a two-dimensional elliptic airfoil with a steady and pulsatile upstream flow and a high laminar Reynolds number (Re = 14,300).

(4) Three-dimensional flow in curved ducts, both with rectangular and circular cross-sections.

(5) Flow over a submarine body at an incidence of 0^o and 20^o.

Additional details of these validation cases can be found in Ref. (2). A brief summary of preliminary results for two validation cases is given below:

Flow Over an Elliptical Airfoil at a High Reynolds Number

The two-dimensional flow over an elliptical airfoil of thickness ratio 1:2.91 at 14^{o} angle of attack and a Reynolds number of 14,300 has been solved to compare with the recent experimental results. Two cases have been considered, (a) steady upstream flow, (b) pulsatile upstream flow. In the second case, a sinusoidally pusatile upstream flow with an amplitude of 5% of the steady part, and a non-dimensional period of T = 6.86 was simulated. A non-orthogonal 0-type grid of 161 x 141 mesh points in the radial and circumferential directions, respectively, has been used. Figure 1 gives the time-evolution of the lift and drag coefficients for the steady and pulsatile upstream flows (it should be noted that in the pulsating case, the time is normalized by the period time T). The analysis of the results and the comparisons with the experimental results will be reported elsewhere.

Flow Over a Submarine Body at Low Reynolds Numbers

The axisymmetric flow over a submarine body has been computed for a low Reynolds number of Re = 1000 and a zero angle of attack. Figure 2 compares the pressure coefficient on the body of the submarine with the computed results of Ryan (Private Communication), while Fig. 3 shows the effect of the Reynolds number on the pressure coefficient. Figure 4 shows the distribution of the pressure coefficient for an incidence of 20^{o}. Figure 5 plots, for the same case, the limiting streamlines (viewed from the rear end of the submarine) and the particle traces (side view).

Moving-Grid Case:

(1) Flow over a circular cylinder with a moving outer boundary.

(2) Flow in a two-dimensional channel with a moving constriction.

(3) Flow in a two-dimensional cavity with a moving piston.

Additional details on these validation cases can be found in Appendix A.

CONCLUDING REMARKS

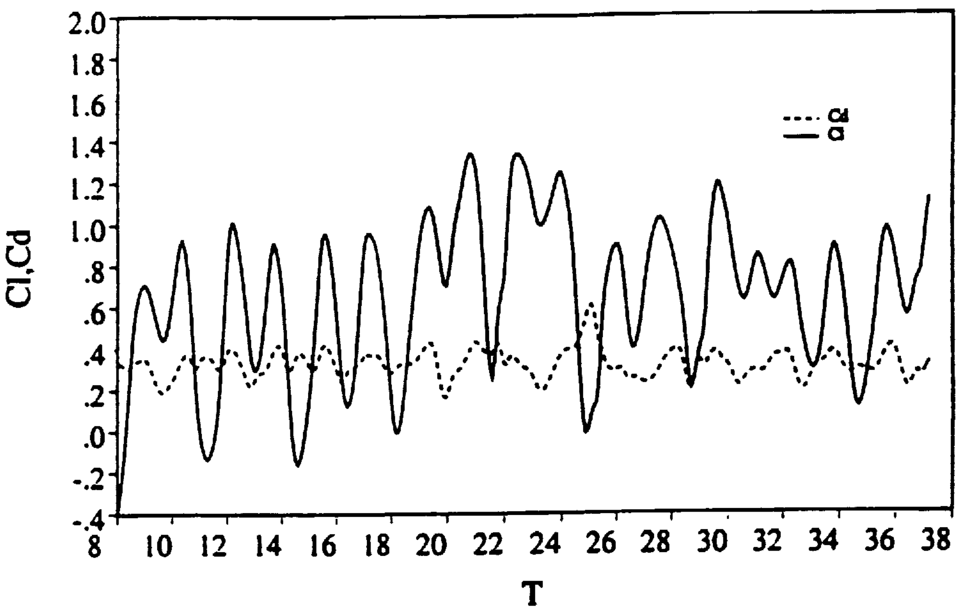
In the present study, a fractional step solution method of the time-dependent, viscous and incompressible Navier-Stokes equations has been extended, enhanced and validated for both fixed and moving generalized coordinate systems. The method has been used to simulate time-periodic vortical flow fields. Investigation of these flows by novel analysis methods that are being developed by the author, may advance the understanding of the complex vortical flow phenomena found in pulsating flows.

The study has demonstrated the capabilities of the present fractional solution method in simulating accurately complicated incompressible time-dependent viscous flow fields.

REFERENCES

1. Rosenfeld, M., Kwak, D., and Vinokur, M., "A Solution Method for the Unsteady and Incompressible Navier-Stokes Equations in Generalized Coordinate Systems," AIAA 26th Aerospace Sciences Meeting, January 1988, Reno, Nevada, AIAA paper 88-0718.

2. Rosenfeld, M., Kwak, D., and Vinokur, M., "A Fractional-Step Solution Method for the Unsteady Incompressible Navier-Stokes Equations in Generalized Coordinate Systems," *J. Comp. Physics,* submitted after revision, 1989.



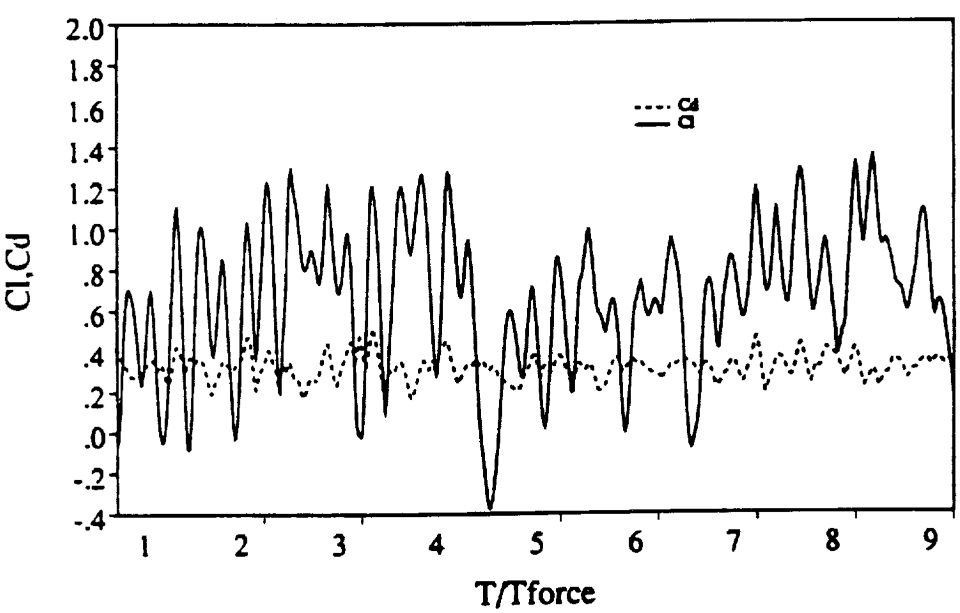


Fig. 1 - Time evolution of the force-coefficients on an elliptic cylinder at 14^{o} incidence and Re = 14,300.

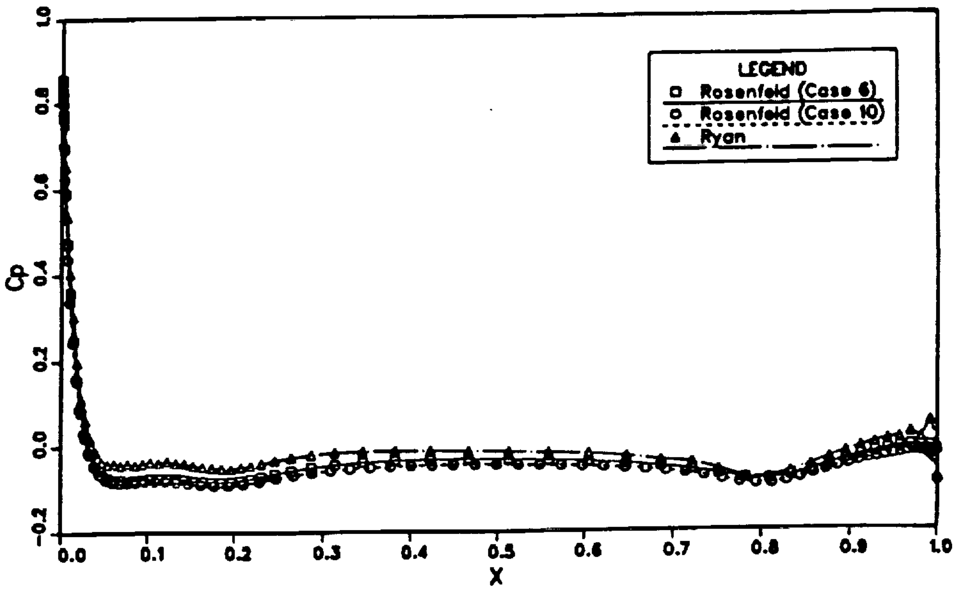


Fig. 2 - Distribution of the pressure-coefficient on the submarine body at 0° incidence.

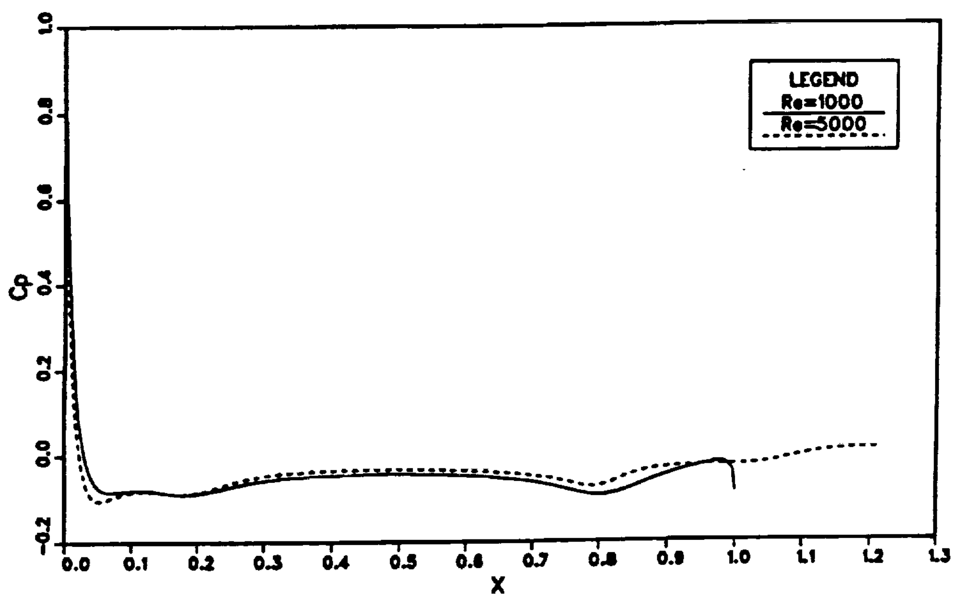


Fig. 3 - Effect of Reynolds number on the pressure-coefficient on submarine body at 0° incidence.

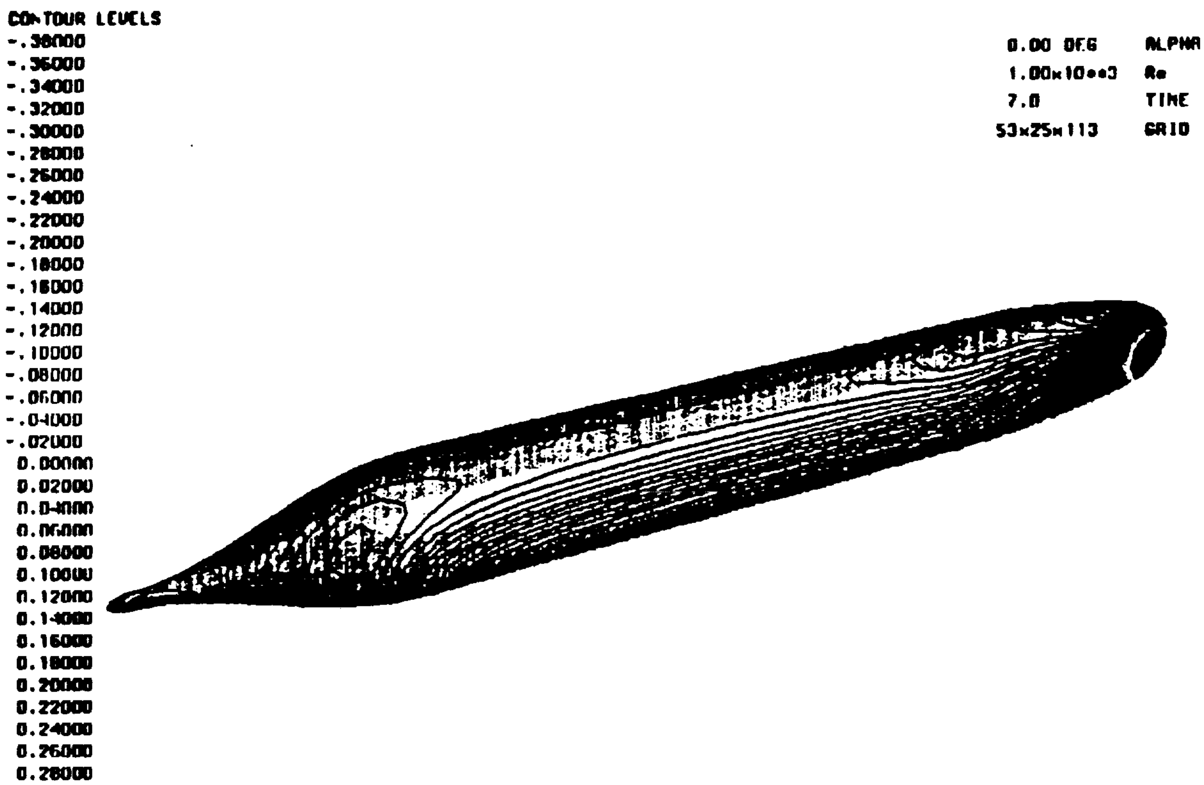


Fig. 4 - Distribution of the pressure-coefficient on the submarine body at 20^{o} incidence.

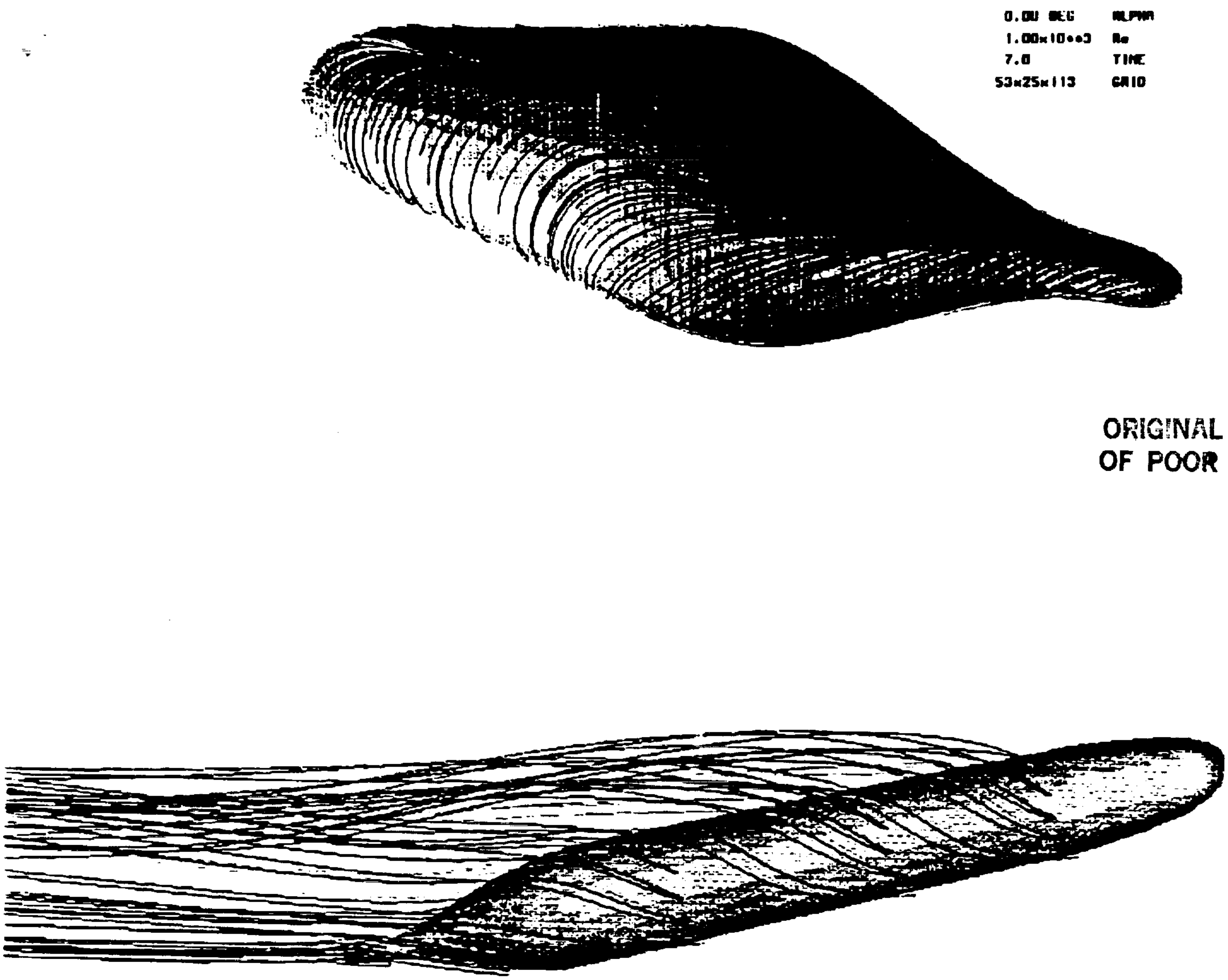


Fig. 5 - Limiting streamlines and particle traces for the submarine body at 20^{o} incidence.